MARS GLOBAL SURVEYOR

Ka-BAND FREQUENCY DATA ANALYSIS

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The Mars Global Surveyor (MGS) spacecraft, launched on November 7, 1996, carries an experimental space-to-ground telecommunications link at Ka-band (32 GHz) along with the primary X-band (8.4 GHz) downlink. The signals are simultaneously transmitted from a 1.5-m diameter parabolic high gain antenna (HGA) on MGS and received by a beam-waveguide (BWG) R&D 34-meter antenna located in NASA's Goldstone Deep Space Network (DSN) complex near Barstow, California. The projected 5-dB link advantage of Ka-band relative to X-band was confirmed in previous reports using measurements of MGS signal strength data acquired during the first two years of the link experiment from December 1996 to December 1998. Analysis of X-band and Ka-band frequency data and difference frequency (f_x-f_{Ka}/3.8) data will be presented here.

On board the spacecraft, a low-power sample of the X-band downlink from the transponder is upconverted to 32 GHz, the Ka-band frequency, amplified to 1-W using a Solid State Power Amplifier, and radiated from the dual X/Ka HGA. The X-band signal is amplified by one of two 25 W TWTAs. An upconverter first downconverts the 8.42 GHz X-band signal to 8 GHz and then multiplies using a X4 multiplier producing the 32 GHz Ka-band frequency. The frequency source selection is performed by an RF switch which can be commanded to select a VCO (Voltage Controlled Oscillator) or USO (Ultra-Stable Oscillator) reference. The Ka-band frequency can be either coherent with the X-band downlink reference or a hybrid combination of the USO and VCO derived frequencies. The data in this study were chosen such that the Ka-band signal is purely coherent with the X-band signal, that is the downconverter is driven by the same frequency source as the X-band downlink).

The ground station used to acquire the data is DSS-13, a 34-meter BWG antenna which incorporates a series of mirrors inside beam waveguide tubes which guide the energy to a subterranean pedestal room, providing a stable environment for the feed and electronics equipment. A dichroic plate is used to reflect the X-band energy and pass the Ka-band energy to another mirror. The RF energy for each band is then focused onto a feed horn and low-noise amplifier package. After amplification and RF/IF downconversion, the IF signals are sent to the Experimental Tone Tracker (ETT), a digital phase-lock-loop receiver, which simultaneously tracks both X-band and Ka-band carrier signals. Once a signal is detected, the ETT outputs estimates of the SNR in a 1-Hz bandwidth (Pc/No), baseband phase and frequency of the signals every 1-sec.

Between December 1996 and December 1998, the Ka-band and X-band signals from MGS were tracked on a regular basis using the ETT. The Ka-band downlink frequencies described here were referenced to the spacecraft's on-board USO which was also the X-band frequency reference ($f_{Ka} = 3.8\ f_x$). The ETT estimates of baseband phase at 1-second sampled time tags were converted to sky frequency estimates. Frequency residuals were then generated for each band by removing a model frequency from each observable frequency at each time tag. The model included Doppler and other effects derived from spacecraft trajectory files obtained from the MGS Navigation Team. A simple troposphere correction was applied to the data.

In addition to residuals, the USO frequencies emitted by the spacecraft were estimated. For several passes, the USO frequencies were determined from X-band data and from Ka-band data (referred to X-band by dividing by 3.8) and were found to be in good agreement. In addition, X-band USO frequency estimates from MGS Radio Science data acquired from operational DSN stations were available for comparison and were found to agree within the 1 Hz level. The remaining sub-Hertz differences were attributed to the different models and software algorithms used by MGS Radio Science and KaBLE-II. A summary of the results of a linear fit of the USO frequency versus time (day of year) is presented in Table 1 for an initial segment of passes.

Table 1
Linear-Fit Results For Passes Between December 1996 and May 1997

Data Set	Slope (Hz/Day)	Offset (Hz)	Time Ref. (Days past 01/01/96))	Number of Observations
DSS-13 X-band	0.251±0.004	28.97±0.13	432.38	18
DSS-13 Ka-band	0.263±0.004	29.26±0.14	432.38	11
Radio Science X-band	0.252±0.003	29.11±0.10	432.38	8

Table 2 summarizes Allan deviations $\sigma_y(\tau)$ for τ = 1, 10, 100 and 1000 sec for the X-band frequency residuals, and the Ka-band frequency residuals for a pass conducted on January 17, 1997. Also provided in Table 2 are the pre-flight USO Allan deviation measurements, and the differenced (f_x-f_{Ka}/3.8) frequency residuals. The X-band and Ka-band Allan deviations are in good agreement with each other and are in reasonable agreement with pre-flight values for the USO except at τ = 1000 sec. The Allan deviation at 1000-s is dominated by unmodeled dynamic motion of the spacecraft where the residuals clearly show trends attributed to the rotation of the HGA electrical axis about the mechanical spacecraft spin axis offset from the direction to the earth. Typical frequency residuals for the individual frequency bands of most other passes were dominated by thermal noise at lower time scales due to lower SNR's.

For passes where Ka-band is coherent with X-band, the received downlink Ka-band frequency is an exact factor of 3.8 times the X-band received frequency. By taking frequency differences across identical time tags of the form f_x-f_{Ka}/3.8, all non-dispersive error contributions, including troposphere and unmodeled dynamic spacecraft motion, cancel out in the resulting difference residuals. The remaining noise sources include thermal noise (significant at small time scales) and charged particles (which dominate at higher time scales). The difference frequency residuals are effectively a measure of the charged particle effect on the X-band link since the effect at Ka-band is significantly smaller (by the ratio of the frequencies squared). The X-band signal strength (56 dB-Hz) and Ka-band signal strength (53 dB-Hz) were comparable for pass 97-017. The difference frequency residual Allan deviations for 10, 100, and 1000 seconds for pass 97-017 significantly exceed predictions based on thermal noise, and are thus attributed to charged particle effects on the X-band link.

For all of the KaBLE-II passes conducted for which significant time periods of coherent X-band and Ka-band data were acquired, the Allan deviations of the difference data type (f_x-f_{Ka}/3.8) were estimated for time intervals of 1, 10, 100 and 1000 seconds. The Allan deviation for the shorter time intervals were generally in agreement with the predictions based on thermal noise. The 1000-s Allan deviations were attributed to charged particles, which far exceeded thermal noise contributions. A general trend was observed showing the 1000-s Allan deviation decreasing as the solar elongation angle is increasing (from 6° to 170°) as expected. The majority of the 1000-s Allan deviation data points at large solar elongation angles (above 160°) were in good agreement with predictions (6×10^{-15}) for the anti-solar direction at X-band. These observed Allan deviations of the difference frequency are thus consistent with expected solar plasma effects on the X-band link

Table 2
97-017 Allan Deviation Summary

τ (Sec)	X-band $\sigma_y(\tau) \times 10^{13}$	Ka-band $\sigma_y(\tau) \times 10^{13}$	USO Pre-flight $\sigma_y(\tau) \times 10^{13}$	X-Ka/3.8 $\sigma_y(\tau) \times 10^{13}$
1	1.15	1.11	1.2	0.36
10	1.01	1.00	0.64	0.12
100	0.96	0.97	0.72	0.06
1000	3.91	3.93	0.89	0.09

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